3

WIRELINE SYSTEMS AND TECHNOLOGY

In a wireline system, the user interface to the communication system involves a physical connection via some fixed transmission medium. This transmission medium may be in the form of pairs of copper wire, coaxial cable, or fiber optic cable. The type of transmission medium used presents some fundamental limitations on the bandwidth, and hence the type of telecommunication services, that can be supported. In general, systems using fiber optic cable can support the largest bandwidth, systems using coaxial cable can support the next largest bandwidth, and systems using copper wire pairs can support the smallest bandwidth. Aside from the transmission medium itself, the equipment required to facilitate transmission over this medium also limits the bandwidth and type of telecommunication services that can be supported.

There are three principal types of wireline networks in the United States today: the public switched telephone network (PSTN), the cable TV network, and numerous varieties of computer networks. Each of these types of wireline networks was initially designed to provide primarily one specific telecommunication service. For example, the PSTN was developed to provide two-way voice communication to as much of the population as possible. The cable TV network was developed to provide a one-way, multiple-channel video programming service. Computer networks evolved around the efficient transmission of data. While these systems were initially developed to provide a particular telecommunication service, different forms of telecommunication services are now being provided over these networks. As an example, the PSTN is being used to provide fax service and low-speed data communications through the use of voice-band modems. Voice and data communications over cable TV networks are being considered. Computer networks, with the capability to transmit data, are routinely used to transmit both digitized voice, audio, and video (primarily still images at the present time). The most common example of a computer network currently being used to transmit data, voice, audio, and images is the Internet.

In this section, the three principal types of wireline networks are discussed. Descriptions of these networks and the systems and technologies used in these networks are presented with particular emphasis on applications in rural areas. Example costs of these systems are given where applicable. The bandwidth and types of telecommunication services that can be supported over these networks are also discussed.

3.1 Public Switched Telephone Network

The PSTN is a telecommunications network that was developed to provide two-way voice communication to many users. Telecommunication networks provide a means of interconnection (via transmission paths) between users allowing all users to communicate with each other. Probably the most fundamental type of network consists of a direct line (sometimes called a link) from every user to every other user within the network. This type of network is called a mesh network. While mesh networks work well for a small number of users, the number of lines required quickly becomes unmanageably large as more and more users are added. Since the PSTN has a tremendous number of users, a different type of network is used. By connecting all users to a central location, and providing a switch to connect any user to any other user, the number of required links can be greatly reduced. This type of network is called a star network.

In the PSTN, telephone lines from users in a given local area all connect to a switching office at a central location called the central office (CO) or end office (EO). The basic network configuration is a star network. The size of the local area is dependent on the number of telephone users in the area. Therefore, in an urban area, a single CO may only connect users within a small area. Conversely, in rural areas, a single CO may connect users spread out over a wide area. At each CO is a switch that is used to connect any user to any other user. The switch sets up and releases the required lines to connect a specific user to another.

Telephones are connected to the CO by the local loop. The local loop typically consists of a drop wire, distribution cable, and feeder cable. The drop wire usually consists of a twisted pair of copper wires coming from the end user's telephone wiring (called premise wiring). Drop wires from a group of users are combined to form a distribution cable. Several of these distribution cables are then combined to form a feeder cable. The feeder cable then provides the connection to the CO (Rowe, 1988, pp. 128-129). The feeder cable is usually a large multipair cable containing up to 2700 copper wire pairs. The distribution cable is usually a smaller multipair cable. Fiber optic cable is beginning to appear as an alternative feeder cable and has been discussed for use in the distribution cable as part of the Fiber to the Curb (FTTC) concept (Calhoun, 1992, pp. 63, 410, 551).

The PSTN in the United States has approximately 20,000 COs. COs, like individual users, could be connected together in a mesh network but because there are so many COs, too many trunks[1] would be required. Therefore, COs are connected together with trunks by a network structure other than a mesh network. Before the breakup of AT&T, AT&T had a five-level hierarchy for connecting COs. In this hierarchy, COs were the lowest-level switching office. Each CO within a given area was connected to a central location called a toll center using a star network. Within a larger area, each toll center was connected to a central location called a primary center again using a star network. This process of connecting lower-level switching offices to a switching office at the next higher level continued, providing two more levels of switching offices (sectional centers and regional centers, respectively). Besides this strict hierarchical network structure, additional trunks that connected switching offices at one level with switching offices of the same or different levels were included to improve circuit availability and reliability.

After the divestiture of AT&T, although the fundamental concepts of a hierarchical network based on a star network with additional interconnecting trunks remained the same, the structure of the PSTN changed. In the current structure of the PSTN, the United States is divided into approximately 165 local access and transport areas (LATAs).[2] Service is provided within each

[1] A trunk is a transmission path connecting two switching offices together.

[2] Some areas in the United States, served entirely by independent telephone companies, are not part of a LATA.

LATA by local exchange carriers (LECs). The LECs include the Bell Operating Companies (BOCs) as well as over 1300 independent telephone companies (Bellamy, 1991; OPASTCO, 1994, Appendix F). The LATAs were defined to place restrictions on the BOCs for carrying traffic between LATAs. Inter-LATA traffic must be carried by long-distance carriers called interexchange carriers (IXCs) and cannot be carried by BOCs. Likewise, an IXC cannot provide intra-LATA service (Bellamy, 1991). The IXC connects to a LATA at a single point called the point of presence (POP) within the LATA. The network structure within the LATAs is determined by the LECs within that LATA. Only one intermediate switching office between the CO and the POP is allowed, however. These restrictions on service, as well as other telecommunication regulations, may be impacted by telecommunication legislation currently pending before Congress.

Trunks providing connections between switching offices are implemented with various transmission media. These transmission media can be either wireline or wireless. Wireline transmission media include multipair copper wire, coaxial cable, and fiber optic cable. Wireless transmission media include microwave radio and satellite.

The various types of transmission media can support signal bandwidths that are much greater than the 4-kHz bandwidth necessary for a single voice channel. In the case of wireline transmission media for a network with a large number of users, it is very inefficient if an individual wire pair, coaxial cable, or optical fiber is used to transmit only one voice signal. Methods of combining and transmitting many voice channels over a single transmission medium have been devised. There are two primary methods for doing this: frequency-division multiplexing (FDM) and time-division multiplexing (TDM). TDM is primarily used with digital signals whereas FDM can be used with either analog or digital signals.

In FDM, the bandwidth of the transmission medium is divided into a large number of channels. Each channel can then carry an individual conversation. In this way, many voice channels can be provided over a single transmission medium. A standard hierarchy for using FDM with voice channels was developed by the Bell System. In this hierarchy, 12 voice channels are initially multiplexed to form a group. Five of these groups are then multiplexed to form a “supergroup” containing 60 voice channels. This process is repeated to generate up to four more levels. At the top of the hierarchy lies the “jumbogroup multiplex” containing 10,800 voice channels.[3]

TDM also allows many voice channels to be transmitted over a single transmission medium. In TDM, the transmission medium is divided into individual time slots. Each voice channel is assigned a particular time slot within a given period of time called a frame. These frames are then transmitted continuously. In this way, a time slice (short segment) of a particular voice channel's traffic is transmitted during each frame.

A T-carrier system uses TDM to send many voice channels over a single transmission medium. A TDM hierarchy was developed by AT&T and is now a North American standard. In this hierarchy, 24 channels operating at a data rate of 64 kbps are multiplexed to form a T1 line. The

[3] Actually, capability up to 13,200 voice channels exists.

T1 line carries data at a rate of 1.544 Mbps. Four T1 lines are multiplexed to produce a T2 line that carries data at a 6.312 Mbps rate. T3 lines operate at 44.736 Mbps and are formed by multiplexing 28 T1 lines. Six T3 lines are multiplexed to form a T4 line operating at 274.176 Mbps. T1 lines consist of a twisted wire pair with regenerative repeaters normally spaced about every 6000 ft. The regenerative repeaters detect and regenerate the transmitted digital data. T2 lines consist of a special low-capacitance twisted wire pair. T3 lines use either microwave radio or fiber optic cable as the transmission medium. T4 lines may use coaxial cable, waveguide, fiber optic cable, or microwave radio as the transmission medium.

Telecommunication services

While the PSTN was developed to provide two-way voice communication, sometimes called plain old telephone service (POTS), other telecommunication services are possible over the existing network. Using the PSTN for services besides two-way voice is attractive since access to the PSTN is quite widespread in the United States. While access in rural areas is not as good as that in urban areas, the PSTN is probably still the most easily accessible and cost-effective large network available to rural telecommunication users. Services other than POTS that can be provided over the existing PSTN include fax, data, and even low-speed video (e.g., the videophone) transmission.

Because the PSTN was optimized for voice transmission, transmission of signals over ordinary telephone lines (called voice-grade channels) is limited to those signals that have a maximum bandwidth of about 3 kHz. In addition, signals transmitted over the PSTN must not have DC or other low-frequency content below about 300 Hz. Transmission of fax, data, and low-speed video over voice-grade channels is accomplished by the use of modems. A modem is required at both the transmit and receive ends of a circuit. The digital signal source at the transmit end is modulated by a modem producing a signal whose frequency spectrum falls within the required 300-3000 Hz for transmission over voice-grade channels. At the receive end, the modem demodulates the signal and reproduces the original digital signal. Data rates up to 28.8 kbps over voice-grade channels can be achieved using voice-band modems.

Integrated Services Digital Network

A major advancement in wireline telephone service is the Integrated Services Digital Network (ISDN). ISDN is an end-to-end digital service that permits transmission of digitized voice, video, and data. ISDN service is based on two different types of digital communication channels: the bearer (B) and the delta (D) channels. Each B channel permits simultaneous transmission of digitized voice, video, or data at rates up to 64 kbps. The D channel is used for overhead functions such as signalling and operates at a data rate of either 16 or 64 kbps. The two common ISDN configurations are the basic rate interface (BRI) and the primary rate interface (PRI). The ISDN BRI consists of two B channels and one D channel and operates over a single copper wire pair. Because the ISDN BRI line consists of two separate data channels, it can support simultaneous operation of two communications devices such as a telephone and a computer. The ISDN BRI line can also utilize inverse multiplexing to combine the two B channels and provide a data rate capability of up to 128 kbps. ISDN PRI consists of 23 B channels and one D channel and can provide data rates of up to 1.472 Mbps by combining the B channels. ISDN PRI operates over a T1 line.

Rural telephone service

Providing access to the PSTN via wireline in rural areas can be difficult. Obstacles to providing wireline service include extremely long distances from the CO, difficult terrain, and unavailability of material for poles to run cables. These obstacles make wireline service very costly in certain rural areas and can also cause difficulties in maintenance and reliability.

The average cost of installing a copper loop is quite expensive. Calhoun (1992, pp. 77-78) cites average costs of up to $1800 per loop. In rural areas it is common to have costs that range from $3000 to $6000 per copper loop.

A common way of reducing the costs of providing telephone service to rural users has been the party line, where a single telephone line is shared by more than one household. Problems associated with a party line are the lack of privacy and the decreased availability of the telephone line. The percentage of party lines (reported by Rural Electrification Association borrowers) has decreased substantially from 1989 to 1993. The percentage of two-party lines fell from 0.8 to 0.3% during this time period. Similarly, the percentage of four-party (or more) lines fell from 4.0% to 0.9% over this time period (Rural Electrification Administration, 1994, p. 17).

Rural telephone service differs from urban service in other ways also. The penetration of telephone service (for the March Quarter, 1992) was 94.5% in Metropolitan Statistical Areas (MSAs) but 91.7% in Rural Service Areas (RSAs; OPASTCO, 1994). Penetration of telephone service is defined here as the number of households that have telephone service within an area divided by the total number of households in that area.

In general, LECs operating in rural areas in the United States provide service to a larger geographic area and to fewer subscribers than LECs operating in urban areas. According to OPASTCO (1994), there is a very large difference in the average number of subscribers per route mile and square mile between rural LECs and BOCs. While the BOCs average 130 subscribers per route mile, the rural LECs average 6.3 subscribers per route mile. Similarly, the BOCs average more than 330 subscribers per square mile while the rural LECs average 4.4 subscribers per square mile.

3.2 Cable Television

Cable television's origin is in Community Antenna Television (CATV). These systems were developed to distribute broadcast television signals in areas where they could not be acceptably received. By the late 1960's, nearly all the areas that could benefit from CATV had been covered and CATV growth nearly stopped.

In the mid 1970's, the ability to receive television signals from satellites breathed new life into the industry. Now channels could be made available over cable that were not broadcast in the local area (and therefore not receivable). Cable television's growth accelerated and continues to this day. Now, cable television service is enjoyed by nearly 60 million U.S. households, representing a market penetration of over 60%. Cable service is available to 95% of U.S. households (Ciciora, 1995). There are 11,800 operating cable systems in the United States that serve 34,000 communities (Broadcasting & Cable Yearbook, 1995).

Until the advent of fiber optics and more recent advanced twisted-pair technology, coaxial cable was the only transmission line capable of providing a long-distance, high-bandwidth communication channel. It was therefore the technology of choice to distribute television signals. It is the use of coaxial cable that resulted in the common name for this service, "cable television."

The use of coaxial cable gives cable television its distinctive features and capabilities as a communication link to the home. The typical system uses a tree structure of coaxial cable to distribute multiple channels of video from a central source called the "headend." Amplifiers and power splitters are used as needed. Typically, the system is only capable of carrying signals one way, "downstream" to the home.

The number of television channels that a system is capable of carrying depends on the bandwidth of the amplifiers and the distance between them. Operating frequency ranges, bandwidths, and the maximum number of potential television channels (NTSC) are given in Table 3-1.

Current rural services

The expense of deploying a cable television system can be divided into two basic parts. The first part is the cost of the headend which is primarily a fixed cost regardless of the number of subscribers or "houses passed" (i.e., houses that the cable passes by and can access service). The second part is the cost of the installation of the cable for distributing the television signals; this is primarily proportional to distance and therefore to the number of houses passed (assuming a uniform housing density).

It is these expenses that limit the number of rural areas in which cable television service can be economically provided. A typical headend cost is $200,000 to $300,000. The cost of laying cable in rural areas ranges from $7000 to $10,000 per mile. In urban areas, costs can range up to $100,000 per mile or more. The average monthly fee for basic service is $23 (Broadcasting & Cable Yearbook, 1995).

Table 3-1. Cable Operating Frequencies and Maximum Number of Channels

Operating Frequencies (MHz)	Bandwidth (MHz)	Maximum Number of Channels
50 - 220	170	22
50 - 270	220	30
50 - 330	280	40
50 - 400	350	52
50 - 450	400	60
50 - 550	500	80
50 - 750	700	110
50 - 1000	950	150

There is no hard limit on the size of rural community below which cable service cannot be provided. Although, the above costs would indicate that only communities providing more than 5000-7000 subscribers would be economical, there are many factors to be considered including monthly fees, number of channels provided, and percentage of market penetration. For example, one system was deployed to provide service to only 70-80 subscribers. The headend cost was kept to only $35,000 through the use of excess equipment.

Of course, in rural areas the density of homes becomes an issue. Cable television service providers are generally unwilling to extend their cables into rural areas where the subscriber density is less than 10 per mile. Therefore, individual farm houses are not expected to have access to cable service given the current economics.

In summary, many rural communities already have or could have access to cable television. Systems in smaller communities may provide a fewer number of channels in order to reduce costs. Smaller communities may be at a disadvantage when negotiating with cable providers since larger communities may be perceived as offering more attractive returns on investment capital. Individual farm houses are too sparsely located for economical access to cable.

Future rural services

Many cable systems are currently upgrading to a Hybrid Fiber/Coax (HFC) network architecture. In HFC networks, optical fiber is used for the trunks of the system that bring the television signals to the neighborhood where they are distributed on coaxial cable. A simple schematic of the HFC architecture is shown in Figure 3-1. The use of fiber makes it possible to extend the range of the network, economically increase the bandwidth, improve picture quality, and improve reliability. The plans for other telecommunication services to be provided in the future over cable television systems require the HFC architecture.

The partitioning of the available bandwidth in a cable system for different services and channels is called the frequency allocation of the cable spectrum. The cable spectrum below 5 MHz is not used. The cable spectrum from 5-50 MHz is planned to be used for "upstream" signals from the home. Providing a guard band for filtering results in the availability of spectrum from only 5 MHz to about 40 MHz for upstream communication in the United States. Most of the cable spectrum from 54 MHz to the highest frequency of the particular cable system is divided into 6-MHz channels that are used to provide the television signals to a user's television.

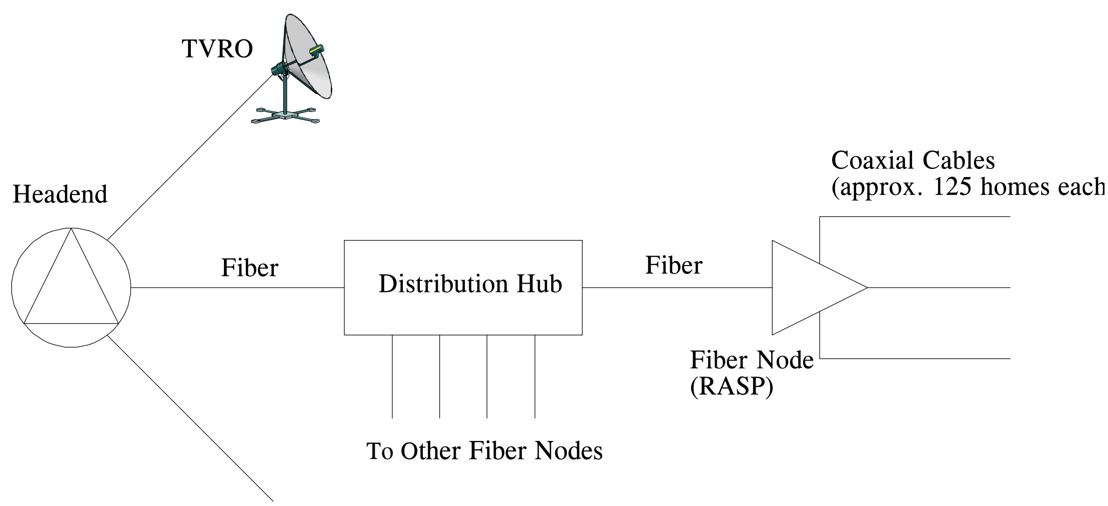

Figure 3-1. Example Hybrid Fiber/Coax architecture.

Many new telecommunication services to be provided over cable systems in the future will require two-way communications. The upstream communication from the home will take place in the 5-40 MHz frequency range. The downstream communication will most likely take place between the highest frequency television channel provided and the highest usable frequency in the cable. However, the design of the system is capable of carrying the downstream signals anywhere in the downstream passband from 54 MHz to the highest usable frequency. Such new services will decrease the maximum number of television channels the cable system can provide and in some systems may reduce the number of channels actually provided.

Today, cable subscribers often need no user premises equipment other than a cable-ready television or VCR. If the television is older and not cable-ready or the user subscribes to certain premium channels or services, a set top box for the TV is required. However, the new telecommunication services will require Premises Interface Devices (PIDs) to terminate the cable network and provide the interface to the upstream and downstream frequency bands.

Although almost all systems are currently only capable of carrying downstream signals, nearly all systems were designed to carry upstream signals as well, providing the capability for enhanced services in the future. The amplifier housings that were deployed accommodate a plug-in amplifier module for upstream signals from the home. This feature will reduce the costs of future telecommunication services provided through cable.

Any deviation from the current cable spectrum frequency allocation plan to accommodate future telecommunication services will require major modifications to the cable plant and will be expensive. However, with forethought, the cable system can evolve to a future system that includes a different frequency plan. This evolution of the system will distribute the major costs involved over many years.

The plans for future telecommunication services discussed in this report are compatible with the current cable spectrum frequency allocation plan. They are telephone service (both wireline and wireless), High Speed Data Services (HSDS), and Video Telephony Services (VTS). The network management of these services is planned to include dynamic frequency assignment in the upstream and downstream bands in order to make maximum use of the spectrum available. In addition, the network management is planned to allow the phased deployment of services beginning with POTS. The network management must also support changes in the current television services, i.e., advanced television (ATV), video on demand, and interactive video. Technical details of the cable industry's plans for these future telecommunication services can be found in Cable Television Laboratories, Inc. (1994). The details of VTS are yet to be determined and are not discussed.

Cable telephone service

POTS is expected to be the first telephony service made available over the HFC architecture. Access to the service would require user premises equipment, PIDs, to interface between the radio frequency signals on the cable and standard telephone equipment. This same equipment may include modules for interfacing to other telecommunication services.

Typically, the number of voice-bandwidth channels that need to be made available on a cable depends on the number of houses passed by the cable and the quality of service desired. The performance objectives require a probability of blocking of .0005 or better. Allowing for the possibility of a 100% subscription rate, and for 125 houses passed by a single cable, each cable will need to carry 23 trunked, duplex voice channels for an estimated traffic intensity of 3 CCS (hundred call seconds per hour) per subscriber.[4]

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[4] The number of subscribers served and the quality of service for general telecommunication systems ae discussed in more detail in Section 4.5.

Connection to the PSTN is made from the headend or distribution head to the Local Exchange Carrier (LEC). Calls from one cable telephone customer to another could be carried only on the cable.

A number of fixed, trunked, duplex voice channels could be dedicated to the telephone service alone. Only an estimated 250 kHz to 1.25 MHz of bandwidth would be needed in both the upstream and downstream bands. However, because of the limited amount of spectrum available for upstream signals, it is preferable for the channels to be dynamically allocated so that the spectrum is available for other services when not in use for telephone service. This can be done very effectively with the wireless telephone service discussed below.

Personal communication services

Individual cable television companies and consortiums comprised of cable companies were the largest winners of spectrum in the recent auctions held by the FCC for broadband personal communications services (PCS). (More information on PCS can be found in Section 4.5.3 of this report.) This will allow a number of cable companies to offer wireless telephone service.

The typical, initial deployment of this service will include several cellular telephone-like base stations that cover large cells of 10-20 miles or more in radius. Areas within or near these cells where radio signal coverage is not adequate will be covered by Remote Antenna Devices (RADs). The RAD will hang from overhead cables and will therefore only be deployed where cable television service is provided. Each of these RADs is expected to cost about $500, have a transmitter power of about 100 milliwatts, and cover an area of up to 1000 ft in radius.

Each RAD will operate as an up-converter for transmission and a down-converter for reception, (i.e., the radio frequency signal in the PCS band will not be significantly changed, but only converted to or from a suitable frequency for transmission down the cable). The signals will be processed for reception or generated for transmission at the Fiber Node (FN) in a Remote Antenna Signal Processing (RASP) unit.

At least one large consortium has selected a code-division multiple access (CDMA) version of PCS for deployment. CDMA systems (using RAKE receivers) benefit from multiple, delayed copies of the desired signal which often degrade the performance of other technologies. Thus, CDMA is a good choice for the simulcast approach to be used in providing PCS over cable television systems. In simulcast, all of the RADs on a single cable will be required to use the same PCS frequencies. The handheld unit could receive signals from several RADs at the same time. Likewise, several RADs could receive the signal from one handheld unit. These signals, with varying delay times due to the different distances involved, will be added together and sent to the RASP.

It is possible in an initial deployment to have several cables on the same simulcast frequency. As capacity needs increase, various combinations of the cables could be assigned different frequencies. This would decrease the initial deployment costs while allowing for increases in capacity when they are needed.

The frequencies needed in the cable to communicate between the RASP and RAD can be dedicated. However, the industry is hopeful that these frequencies can be dynamically allocated so that the unused spectrum can be made available for other services.

High speed data services

Bandwidth requirements between computer networking service users and information service providers is usually very asymmetric. That is, the user usually makes a simple request while the information service provider responds with the requested item which is usually much larger (e.g., a home page, an image, a video clip, or a text file). Spectrum availability in the cable matches this situation rather well. The spectrum in the upstream band is relatively limited. However, even after providing wireline and wireless telephone service, 10 MHz or more of spectrum bandwidth is available for HSDS. This is more than an adequate bandwidth for providing all of the common computer networking services available today. In the downstream direction, much more spectrum is available, although little more may be needed for the foreseeable future.

The cable industry plans to provide HSDS are quite ambitious. Through the use of user premises equipment, PIDs, connections for all popular user data terminals and LANs will be provided. This includes simple serial port connections or Ethernet connections to personal computers. In addition, even dial-up access (through the cable telephone service) will access the HSDS. Connection to the Internet and other information services will be included.

Advanced television, video on demand, and interactive video

Advanced television means digital television and High Definition Television (HDTV). The transition from the current NTSC standard television signal to digital television using the Motion Pictures Experts Group (MPEG-2) compression will greatly increase the number of television channels that can be provided over the cable. Although, compression rates have been proposed that allow 10 channels to be delivered in the 6-MHz bandwidth currently used for one NTSC channel, four channels in place of one is more commonly accepted and will be assumed here. This will allow an increase in the number of channels provided from the current maximum of 150 to as many as 600 channels. In the industry, 500 channels are envisioned, probably because the remaining spectrum is to be allocated for the downstream part of the new telecommunication services. It is expected that a set-top box or other PIDs will be needed for digital television.

In the future, cable will provide HDTV service. As is planned for broadcast television, each HDTV signal will require a 6-MHz channel after compression. Thus, four compressed, digital NTSC channels will need to be given up for each new HDTV channel. After HDTV service begins, the spectrum availability in the cable could change from being relatively abundant to scarce. However, improved compression of NTSC signals or other technologies potentially could relieve this situation.

Video on demand and interactive video will be provided through some of the 500 compressed, digital television channels available (i.e., it is expected that not all of these channels will be dedicated to regular cable programming). Video on demand will probably start out as a near-video-on-demand service. Selected, popular programs or movies will be started at intervals, e.g. every 10 minutes, using several video channels. This will initially be offered as an improved pay-per-view service.

3.3 Computer Communication Networks

Advances in wide area network technology and steadily increasing demand for computer connectivity have encouraged the development of a wide variety of wireline computer communication networks. These networks are operated by LECs, IXCs, and private carriers (Data Communications, 1994a). These networks offer various transport and switching capabilities based on the technologies they use, and have varying requirements for access from the customer premises.

3.3.1 Circuit-switched Technology

Circuit-switched technology establishes a temporary connection that permits exclusive use until the connection is released (Rowe, 1988). The connection is established on demand and involves one or more intermediate switching nodes. Because the actual carrier facilities used in routing the call depend on the facilities available at the moment, circuit quality may vary significantly. Users are typically charged based on the amount of time they use a connection.

Many carriers will set aside circuits in their network for dedicated use by their customers. These circuits are often referred to as leased lines. They are intended for applications that generate a relatively constant flow of data. The primary advantage of a dedicated circuit is that it is engineered by the carrier, installed, and left in place so that the same facilities are always used. This means that once the circuit is operating correctly, it should continue to operate reliably for long periods of time. Users are charged a flat fee for a dedicated circuit, whether they use it or not.

Circuit-switched computer communication networks offer transmission capabilities that fall into three main ranges:

- 1200-28,800 bps using modems (this capability is available through the circuit-switched analog voice-grade PSTN).
- 56 kbps to 45 Mbps using T-carrier equipment.
- Up to 155 Mbps using synchronous optical network (SONET) equipment (dedicated circuits only).

Dedicated circuits are the dominant choice for data communication networking in the United States. Revenue for carriers in 1995 is projected to be nearly $8 billion. Carrier revenue for switched digital circuits (including ISDN) is projected to be $228 million in 1995 (Data Communications, 1994b).

3.3.2 Packet-switched Technology

Packet-switched technology segments data into relatively small blocks before transmission. Each block, known as a packet, contains user data and control information. The control information typically includes flags marking the beginning and end of the packet, source and destination addresses, sequence number, and error detection/correction codes. Packets are routed through the network one at a time, and may arrive at their destination by different paths and out of sequence. The computer at the receiving node is responsible for reassembling the packets into the correct sequence before passing them on to the user. A certain amount of transmission delay is inherent in packet-switched networks, but they make efficient use of network resources for bursty data traffic that is not highly time-sensitive.

Commercial packet-switched networks operate according to the well-established X.25 international standard. The standard was developed during the 1970's for use over electrically noisy analog copper transmission facilities that tended to introduce errors. Every switching node in an X.25 network goes through a rigorous, time-consuming procedure to check the validity of the structure and routing of a packet before passing it to the next node where the process is repeated. The technique has been widely and successfully implemented, but it is limited to a speed of 64 kbps, and it is not suitable for the transmission of voice or video information.

Despite its limitations, packet-switched technology is appropriate for many data communication applications, and its use continues to grow at approximately 10% annually; carrier domestic revenue for 1995 is projected to be just over $1 billion (Data Communications, 1994b).

3.3.3 Fast Packet-switched Technologies

Needs for LAN interconnection and the transmission of voice, data, image, and video information have helped to foster the development of two fast packet-switched technologies: frame relay and cell relay.

Frame relay

Frame relay is essentially an enhancement of X.25, and takes advantage of the widespread implementation of fiber optic communication links by long-distance carriers. Fiber is much less prone to introducing errors in a data stream, so frame relay does not use most of X.25's extensive checking at switching nodes; these processes are instead completed by the sending and receiving devices. Frame relay is designed to operate at speeds up to 1.5 Mbps, but may be enhanced to operate at higher speeds in the future. It is particularly well-suited to the interconnection of LANs which generate bursty traffic consisting of variable-length frames of data. Frame relay accepts this traffic as is, adding only a wide area network address at the front and its own check sequence at the end of each frame. Frame relay interfaces for customer premise equipment such as routers, bridges, and hubs are available from a number of vendors. Frame relay switches are also available, and numerous carriers offer public frame relay services. As the technology and standards are refined and carrier tariffs are clarified, frame relay networks are expected to replace many X.25 networks during the next several years. Frame relay is not well-suited to the transmission of real-time voice or video, however, because of the variable delay allowed between frames.

Carrier revenue for frame relay services is growing at annual rates in excess of 200%, and 1995 revenue is projected to be nearly $600 million (Data Communications, 1994b).

Cell relay

Cell relay is a high-bandwidth, low-delay, switching and multiplexing packet technology. Its combination of simplified error and flow control, fixed-length cells which allow high-speed switching, and procedures for allocating network bandwidth enable it to support voice, data, image, and video traffic. Asynchronous transfer mode (ATM) is the international standard implementation of cell relay. It is defined to work over different physical media and at speeds ranging from 45-622 Mbps, with extensions to lower and higher speeds possible. Vendors are beginning to produce ATM network equipment and carriers are beginning to assemble ATM networks. Current service offerings are developmental in nature, however, and it is expected to take several years for the technology to mature. Significant infrastructure investments by carriers will be required to make ATM widely available.

Switched multimegabit data service (SMDS) is another standards-based implementation of cell relay. It is being implemented primarily by large LECs to provide connectivity within their service regions, mostly in major metropolitan areas. Access and transmission speeds range from 1.5-45 Mbps. The future of SMDS is somewhat cloudy — IXCs appear to be more interested in implementing ATM rather than providing wide area connectivity for SMDS; given the potential of ATM for implementation at the LAN level, network managers may prefer local access to ATM rather than SMDS. The two implementations of cell relay are similar, however, and there is a clear migration path for carriers to move from SMDS to ATM.

Carrier revenue for ATM is projected to be $40 million in 1995, a 400% increase over 1994. SMDS 1995 revenue is projected to be $27 million, an increase of 270% over 1994 (Data Communications, 1994b).

3.3.4 Rural Access to Computer Communication Networks

The analog voice-grade circuits provided by LECs in rural areas offer some circuit-switched data communication capability, but maximum transmission speeds are currently limited by modem technology and the bandwidth of these circuits to 28,800 bps. In many cases, rural circuit quality is not adequate to support this speed. Rural party lines are not well-suited for data communication.

The access points for computer communication networks (known as points of presence, or POPs) are usually located in larger metropolitan areas. Rural users can usually use analog voice-grade circuits to access POPs for X.25 packet-switched networks. A limited cable plant may prevent a LEC, however, from providing enough circuits to a rural business for both voice and data communication.

Access to POPs for high-speed circuit-switched or fast packet-switched computer networks require high-quality digital circuits capable of supporting transmission speeds of 56 kbps and above. These circuits are not generally available from LECs in rural areas. In some cases, users can convince a LEC to bring in a high-speed circuit (Zeiger, 1995). In other cases, rural users will need to explore alternatives to bypass their LEC to reach a POP. These alternatives may include the use of private fiber optic or microwave radio circuits, or the use of a commercial satellite service (Office of Technology Assessment, 1991).